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**The Commander's Edge
Intelligent Agent Software Applied to Battlefield Problems**

L. B. Scheiber, Project Leader

September 2000

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IDA Document D-2475

Log: H 00-001684

20010613 032

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The Commander's Edge
Intelligent Agent Software Applied to Battlefield Problems

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PREFACE

The Commander's Edge effort was initiated to provide a first order look at how information technology, specifically intelligent agents, is being integrated into the systems to aid the commanders on the battlefield. It was not intended to be an in-depth study or an assessment of how well it is being done. This paper is provided for the sole purpose of making available the material the team found in its very brief look since the material can provide significant background for studies which follow.

The team recognizes that due to time and resources constraints it most likely did not reach every on-going effort in each of the Services and Agencies. However, it is believed that sufficient research was accomplished to capture the sense of what

is being done in these organizations and what can be expected on the battlefield in the near-term.

The project team wishes to thank the technical review committee, Dr. Joan F. Cartier, Dr. Ronald A. Enlow, Mr. Robert C. Holcomb, Mr. John F. Sandoz, Dr. Jeffrey E. Schofield, Dr. John R. Shea, and Mr. Louis L. Simpleman, for their very helpful comments and their encouragement to publish this document.

The team also extends thanks to those people who provided the material presented in this paper. They are listed as points of contact (POCs) in their respective areas in the detailed sections of the document.

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OUTLINE

- SUMMARY
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- BACKGROUND
- ISSUES
- APPROACH
- DISCUSSION
- CHAPTERS
 - Defense Seminars
 - Science & Study Boards
 - Joint Forces Command
 - Services
 - U.S. Army
 - U.S Navy
 - U.S. Marine Corps
 - U.S. Air Force
 - DARPA
 - Sandia
 - Academia
 - Industry and Additional Websites

SUMMARY

Broadly, the objective of this effort was to examine the extent to which the military is developing information technology, specifically intelligent agents, to assist commanders in obtaining decision superiority on the next-generation battlefield. The objective was not to assess current efforts but to develop an understanding of what is being developed and how it is expected to be used.

Clearly, with the increase of information available to battlefield commanders, they will need additional tools with which to make winning decisions in high tempo battles. The emerging networks that the Services are readying for the battlefield constitute a fundamental step into the era of network-based warfare. Networks afford the opportunity to improve the commanders' ability to obtain the information they need, when they need it, and in the proper form.

Intelligent agents would appear to be one tool for obtaining and displaying information in a timely fashion. Thus, we attempt to answer the following questions:

- Can intelligent agents aid in extracting data, in processing data into knowledge useful to the commanders, and in presenting knowledge in a form the commanders can quickly use? Can they do it in a timely fashion?
- Can such intelligent agents be expected to be available in time to support the next-generation battlefield?
- Can this use of intelligent agents be expected to lead to decision superiority on the next-generation battlefield?

The team contacted Joint and Service organizations and DoD agencies involved in the advanced concept and development of battlefield command and control (C²) systems. From these contacts we established the main organizations working on information technology, specifically intelligent agents, including contractors and universities. The team then attended briefings by these organizations, reviewed documentation provided, and met with principals of ongoing agent-based efforts.

In carrying out the study, it became clear that the military expects intelligent agents to provide a significant advantage for warfighters. However, the team found no applications ready for near-term fielding. The study did find two programs directed toward the application of agents to the battlefield: *Control of Agent Based Systems* (CoABS) by DARPA and the Navy and the *Integrated Marine Multi-Agent Command and Control System* (IMMACCS) by the Marine Corps and CalPoly. Both are in early testing. A third program, sponsored by Joint Forces Command, is developing intelligent agents for use in the support of joint testing. It may also have some potential to provide the same type of support on the battlefield. Sandia is also working with intelligent agents. While their efforts are not specifically directed toward the military, they might have utility on the battlefield.

SUMMARY

- **PURPOSE**
 - To develop an understanding, not to make an assessment
- **ISSUES**
 - Where is the military in the application of intelligent agents to battlefield problems?
 - Can intelligent agents aid the commanders? In a timely fashion? Lead to decision superiority? What is their availability?
- **APPROACH**
 - Extensive briefings, visits, and documentation obtained from DoD and Service organizations including Science and Study Boards, contractors, and academia.
- **FINDINGS**
 - Military expects intelligent agents to provide significant advantage for warfighters
 - No applications ready for near-term fielding
 - Navy and Marine Corps testing concepts. JFCOM has effort in development
 - Effort taking longer than expected
 - Growing battlefield complexities and enemy sophistication necessitate we press on – need road map

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SUMMARY (continued)

It was observed that the development of these kinds of efforts are taking longer than originally expected. On the other hand the tools, i.e., hardware, software, and development environments, are getting better.

The answers to the original questions, can intelligent agents help the commanders, etc., are still very unclear. However, it is clear that the amount of information available on the battlefield is rising rapidly, and the military must find ways to provide commanders with information they need, when they need it and in usable form. So press on we must for, although we cannot be

sure of where the efforts will eventually lead us, we can be sure that our future enemies are not standing still, and we certainly do not want them waiting for us when we get there.

To do this efficiently and effectively, a road map detailing the way forward must be developed. It appears that this would require a consolidated effort involving the warfighter to define the problems, and industry and academia to articulate the technology and develop the solutions. The effort might be lead by OSD and JFCOM.

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BRIEFING REPORT

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OBJECTIVE

- EXAMINE THE EXTENT TO WHICH INFORMATION TECHNOLOGY, SPECIFICALLY INTELLIGENT AGENTS, IS BEING DEVELOPED TO ASSIST COMMANDERS IN OBTAINING DECISION SUPERIORITY ON THE NEXT-GENERATION BATTLEFIELD

BACKGROUND

The use of data networks and information technology is expanding at a rapid rate. This expansion is redefining how our businesses operate. Those that fail to make adequate use of the new techniques afforded by this technology are expected to find it difficult to compete in the evolving marketplace.

All of the Services and DoD are developing data networks for the next-generation battlefield. These networks are intended to gather and maintain a great deal of information on the nature of the battle including data on the battlefield's current and future physical condition, such as weather and terrain; data on the enemy, including the position, strength, and reserve capability of its forces, as well as similar data on one's own forces. In some

cases the networks will also contain near-real-time information from sensors. Further, the 1999 DSB Summer Study indicates that information technology, especially intelligent agents, is expected to greatly improve our forces' ability to conduct battlefield operations. A number of recent military speakers at IDA have also indicated that intelligent agents offer a significant potential to improve the military's capability on the battlefield. In addition, it appears that some of the Services are already investigating the potential utility of intelligent agents on the battlefield. This exploration and findings of this investigation are the subject of this paper.

BACKGROUND

- INDUSTRY'S USE OF INFORMATION TECHNOLOGY IS EXPANDING RAPIDLY
- BUSINESSES THAT FAIL TO MAKE ADEQUATE USE OF THIS TECHNOLOGY ARE EXPECTED TO FIND IT INCREASINGLY DIFFICULT TO COMPETE IN THE EVOLVING MARKETPLACE
- DOD AND THE SERVICES ARE DEVELOPING DATA NETWORKS FOR THE NEXT-GENERATION BATTLEFIELD
- THE DSB HAS INDICATED THAT INFORMATION TECHNOLOGY, ESPECIALLY INTELLIGENT AGENTS, IS EXPECTED TO IMPROVE OUR FORCES CAPABILITY TO CONDUCT BATTLEFIELD OPERATIONS
- SERVICES ARE INVESTIGATING THE UTILITY OF INTELLIGENT AGENTS ON THE BATTLEFIELD

BACKGROUND (continued)

Two questions that one might ask at this point are "What are Intelligent Agents?" and "How does this technology differ from that of artificial intelligence?" which was highly touted decades ago but did not live up to its billing. Let us address these questions as they pertain to our mission. We will leave the general, all-encompassing answers to the respective communities.

First, the type of agents we are looking at here are software agents. It is useful to separate them into three classes; we'll use level 0, level 1, and level 2. A level 0 agent is a software program (or a piece of software) that carries out a task that requires no intelligence. That is, if a human carried out the process, one would not associate intelligence with the task. For example, if email arrives in your computer a level 0 agent might put a New Email alert message on your screen. A level 1 agent is a software program that exhibits some level of intelligence. For example, a level 1 agent might provide an intelligent summary of the new email when it provides the alert message. A level 2 agent is a software program that not only exhibits intelligence but also learns. For example, a checker-playing program that deletes bad moves until it doesn't make any more bad moves. See for example, "Some Studies in Machine Language using the Game of Checkers," in *Computers and Thought*, edited by Feigenbaum and Feldman, 1963.

The second question is harder to answer and we will not pretend to answer it head-on. While it is true that artificial intelligence work has been conducted for many decades and, as yet, one sees no earth-shattering results, it does not mean that the world has lost interest in it (e.g., check out the conference

proceeding at www.aaai.org/Library/Conference/AAAI/aaai-library.html). In fact, many of us use some form of it everyday in the search engines we employ to locate information on the Web.

On the other hand, today's computers are faster and more capable than those that existed when ideas for artificial intelligence were first being formulated. We also have better programming languages. However, our problems and needs have also grown.

On the battlefield, for example, new sensors collect larger batches of data everyday. New networks are increasing the speed with which data can be sent to and moved around the battlefield. Warfighters need help in finding and understanding the significance of the major nuggets contained in this already overwhelming pile of data. It is yet to be determined which of the world's problems can be solved with artificial intelligence, but whatever help intelligent agents can provide to our warfighters must be made available to them. That is, we have decided to provide or support our warfighters with a multitude of new sensors. These sensors are capable of generating all sorts of data on enemy positions and capabilities. However, we must also provide warfighters with the capability to transform this data into information they need to make fast, superior decisions—decisions that lead to more expedient, less costly victories. Without a way to transform the data, the warfighter spends too much time trying to decipher the overwhelming amounts of information. Ultimately, this may cause more harm than good.

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BACKGROUND (continued)

- INTELLIGENT AGENTS

- What are they?
- How do they differ from artificial intelligence?

ISSUES

Commanders must be able to obtain the information they require when they need it and in a format they can use. The confounding factors can result in a situation that currently planned tools may not be able to make apparent to commanders—in a timely fashion. Moreover, a potential adversary's long-range offensive weapons and U.S. doctrines that envision employment of widely dispersed forces are expected to cause changes in U.S. C² CONOPS, which dictate needs for improving the commander's C² tools.

Clearly commanders will also need additional tools with which to make critical decisions during a developing crisis and to make winning decisions in high tempo battles. The emerging networks, which are a fundamental step into the era of network-based warfare, afford the opportunity to improve the commanders' ability to obtain the information they need when they need it.

Intelligent agents would appear to be one of the tools for obtaining and displaying that information in a timely fashion. Thus, this paper attempts to answer the following questions:

- Can intelligent agents aid in extracting data, in processing data into knowledge useful to the commanders, and in presenting the knowledge in a form commanders can quickly utilize? Can they do it in a timely fashion?
- Can such intelligent agents be expected to be available in time to support the next-generation battlefield?
- Can this use of intelligent agents be expected to lead to decision superiority on the next-generation battlefield?

ISSUES

- CAN INTELLIGENT AGENTS AID IN PROVIDING USEFUL INFORMATION TO COMMANDERS ?
- CAN THEY DO IT FAST ENOUGH TO HELP COMMANDERS ?
- WILL THEY BE AVAILABLE IN TIME TO SUPPORT THE NEXT-GENERATION BATTLEFIELD?
- CAN THEY LEAD TO DECISION SUPERIORITY ON THE NEXT-GENERATION BATTLEFIELD ?

APPROACH

Elements of the Commander's Edge team first contacted the Joint and Service organizations and DoD agencies involved in the advanced concept and development of battlefield C² systems. From these contacts, we established who are the main organizations working on information technology, specifically intelligent agents, and contractors. Academic organizations involved in technology development as well as websites related to the subject were also noted.

The team then attended briefings by these organizations, reviewed documentation provided, met with principals of ongoing agent-based efforts, met with members of companies engaged in the development of and application of intelligent agents, talked with college professors teaching and/or engaged in

research on the development and application of intelligent agents, and visited public and private websites devoted to providing information on intelligent agents.

For each organization contacted, the team collected the following information: planned and ongoing programs and/or projects involving information technology, specifically intelligent agents; problems being addressed; approach being used; types of agents used or to be used; and references, including documents and POCs. Where this was inappropriate (i.e., when no such efforts were found), the team reported on what they did find in the information technology area.

APPROACH

- IDENTIFY, CONTACT, AND VISIT JOINT AND SERVICE ORGANIZATIONS RESPONSIBLE FOR ADVANCED CONCEPT DEVELOPMENT
- OBTAIN BRIEFINGS & DOCUMENTATION AND HOLD DISCUSSIONS ON ONGOING/PLANNED INFORMATION TECHNOLOGY/INTELLIGENT AGENT PROJECTS
 - Services and Agencies
 - Contractors
 - Academia
- REVIEW STATE-OF-THE-ART IN APPLYING INTELLIGENT AGENTS
- DATA COLLECTION PLAN

DISCUSSION

This discussion consists of three sections: The Vision, The Status, and concluding remarks. However, before starting, it should be clearly noted that this effort was directed toward learning what is being done in the military community to apply intelligent agent technology to support the warfighter. It was not intended to be an assessment of the work in which the Services, Agencies, and other organizations are engaged. Thus, what is contained in this report is meant only to document the findings of this effort; nothing in the document should be taken as criticism of the efforts reported on.

THE VISION

The team attended seminars provided by directors who oversee development and fielding of command and control systems in each of the Services' as well as those from members of the Defense Science Board and the Service Science and

Studies Boards. The general topic of these seminars was the application of information technology to improve the warfighter's capabilities. The team also visited commands and talked with people in the field who are engaged in research on, the development of, and the fielding of these systems. From the directors to the Defense Science Board and the Service Science and Studies Boards to the members of the Service units in the field, the expectation is that information technology will bring about a profound change in the military's capability to conduct battlefield operations. Of all of the aspects of information technology, the one that is expected to have the greatest impact is intelligent agents.

DISCUSSION

THE VISION

- DOD AND SERVICE SCIENCE ADVISORY BOARDS EXPECT INTELLIGENT AGENTS TO PROVIDE SIGNIFICANT ADVANTAGE FOR WARFIGHTERS
- ALL SERVICE VISIONS INCLUDE USE OF INTELLIGENT AGENTS ON THE BATTLEFIELD

DISCUSSION (continued)

THE STATUS

With the above vision in mind, one might expect that work in this area is reaching a stage where it will soon be usable on the battlefield. After all, intelligent agents are merely smart software or, as some refer to it, artificial intelligence; artificial intelligence has been around since the 1950s. However, as this study indicates, nothing is ready to actually enter battlefield testing although work has been ongoing for many years.

On the other hand, the study did find two programs directed toward the application of agents to the battlefield. One by DARPA and the Navy, and the other by the Marine Corps and CalPoly. Both are in early testing. A third program, sponsored by Joint Forces Command, is developing intelligent agents for use in the support of joint testing. It may also have some potential to provide the same type of support on the battlefield. Sandia is also working with intelligent agents. While their efforts are not specifically directed toward the military, they might have utility on the battlefield.

The DARPA/Navy effort is testing DARPA's concept for coordinating the efforts of large numbers of agents. The program, called Control of Agent Based Systems (CoABS), uses a grid approach to handle the interface between the different agents. The grid is able to interconnect agents that use different communications protocols. The agents need not be intelligent. The Navy has been supporting the testing in its series of Fleet Battle Exercises.

For example, the most recent experiment, the third in the series, was to address the movement of data between nodes in a battle group. Specifically, the problem being worked on was the searching of selected intel data for information on time-critical targets (TCTs), and then providing that information to the appropriate organizations in an attempt to diminish the time needed to make a decision in the TCT process. Although the test results appear encouraging, it seems that the challenge is more difficult than anticipated.

The next experiments are to be conducted in the August-September 2000 timeframe and are expected to focus on finding specific information in databases to improve retrieval efficiency. That is, rather than moving a large amount of data, much of which may not be necessary, this effort would seek to find the data that the different processes need when they need it.

The Marine Corps/CalPoly effort, the Integrated Marine Multi-Agent Command and Control System (IMMACCS), is a first-generation example of an adaptive command and control system that has the potential to support planning, execution, and training functions concurrently. It is a collaborative system in which computer-based agents assist human operators by monitoring, analyzing, and reasoning about events in near real-time. It includes a model of the battlespace that represents the behavioral characteristics and relationships among real world entities such as friendly and enemy assets, infrastructure objects, and abstract notions. The agents represent a set of tools that together with the human operator can adjust themselves to the problem situations that cannot be predicted in advance.

DISCUSSION (continued)

THE STATUS

- NO AGENT-RELATED APPLICATIONS TO SUPPORT C2 BATTLEFIELD OPERATIONS IN THE NEAR-TERM WERE FOUND
- SERVICE EFFORTS THAT MAY LEAD TO SUPPORT FOR BATTLEFIELD OPERATIONS FOUND TO CONTAIN SOFTWARE AGENTS, BUT NOT INTELLIGENT AGENTS
- HOWEVER, A GROUP OF NON-INTELLIGENT, BUT COOPERATING, AGENTS COULD EXHIBIT INTELLIGENCE

DISCUSSION (continued)

IMMACCS also uses a network to interconnect the agents. SharedNet, developed by the Jet Propulsion Laboratory, allows users to subscribe to information as well as to send queries. Information subscribed to is automatically pushed to the subscriber as soon as it is available. Queries allow users to pull information as it is needed.

A number of agents have been developed for IMMACCS including ones that monitor logistics; aid in selecting the best weapons to support requests for fire; monitor the status and position of friendly units; monitor position, movement, and actions of the enemy units; monitor the battlefield for hazards as well as enemy sensors; and monitors actions for violations of the rules of engagement.

The Marine Corps has used IMMACCS in its operational exercises since at least March 1999 with some positive results. However, it appears that many more years of development and testing will be required before it will be ready to support operations on the battlefield.

The Joint Forces Command (JFC) has tasked the Institute for Defense Analyses to develop a tool to support the Critical Mobile Targets Cell (CMTC) in the Air Operations experiments. The tool, called the Analyst's Edge, is designed to aid in analyzing sensor data to provide information that can help operators more quickly identify targets such as mobile missile firing units or Transporter Erector Launchers (TELs), missile transporters,

depots, forward operating bases (FOB) and forward operating locations (FOL) and call for strikes against them. In the first phase, the tool will use intelligent agent software to, among other things, aid in identifying TEL hide and reload sites.

The tool is designed to use data from the JFC experiments to provide a capability to perform post-experiment analyses as well as to operate in real-time in an ongoing experiment. It is designed to facilitate the testing of hypothesis as to what information can better help the battlefield operator. For example, how helpful would it be to color an object red if the probability of it being a TEL is 80 percent or greater? Sounds like a good idea. However, it could be that a well-trained team sees things that allow them to kill TELs before their probability reaches 80 percent and, therefore, better training is the key.

If such a tool can be of help to the operators in the CMTC deployed in the experiments, it or a variant might provide similar help on the battlefield.

Sandia is conducting research on multi-agent systems and the various mechanisms of team formation, collective behavior and swarming algorithms that come into play with multi-agent systems. The results of this research, in particular that associated with robots, might be applicable to such battlefield missions as surveillance, reconnaissance, relay communication, target location, and mine-clearing.

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DISCUSSION (continued)

CONCLUDING REMARKS

What can be concluded from what was learned when coupled with that which was already known?

First, there is certainly a great deal of interest in trying to apply intelligent-agent software to solve battlefield problems.

Second, past and current attempts have failed or have taken more time and resources than expected.

Third, today's tools, e.g., hardware, software, and development environments, are much better than those of the past and improving at a rapid rate. As an example, in the early days only main frames had the processing power to carry out intelligent-agent-type functions in a reasonable amount of time. Current PCs exceed the processing capability of those early machines and cost on the order of 1,000 times less.

Fourth, the amount of available battlefield information is rising rapidly. The military must find ways to extract the important nuggets and provide the warfighter access to them in a timely and useful manner if all efforts to get this information to the battlefield are to be worthwhile and not detrimental. However, careful attention must be given to adaptability for both the battlefield and the commander. As operations on the battlefield change, intelligent agents must modify themselves or at least be modifiable to accommodate battlefield changes. This is also true for commanders. Different commanders will look for different responses. The intelligent agents must be adaptable to them.

Fifth, even though work has been ongoing for some time, this is still a relatively new field, which appears to have great potential to improve our warfighting capability. However, much work remains to bring it into realization. It can be expected that, in the future, the work done to date will appear as little more than a start. However, many worthwhile efforts start with some initial steps, which might be considered poorly guided by those joining the efforts at a later date. Thus, when pushing frontiers forward, these initial steps are necessary as no one really knows where the real path lies and, while it might take the researchers time to find the "best" path, without the so-called feeble efforts associated with the first steps, very little of any worth would ever get done.

Sixth, the answers to the issues posed in the beginning of this study are far from clear. It would seem that the answers must be yes, but it seemed that way when all of this began.

- Can intelligent agents aid in extracting data, in processing data into knowledge useful to the commanders, and in presenting knowledge in a form the commanders can quickly use? Can they do it in a timely fashion?
- Can such intelligent agents be expected to be available in time to support the next generation battlefield?
- Can this use of intelligent agents be expected to lead to decision superiority on the next generation battlefield?

DISCUSSION (continued)

CONCLUDING REMARKS

- HIGH INTEREST
- HIGH RESOURCE REQUIREMENTS
- IMPROVING DEVELOPMENTAL ENVIRONMENTS
- WARFIGHTERS NEED AUTOMATED SUPPORT TO COPE WITH EXPANSION OF INFORMATION AVAILABLE ON BATTLEFIELD
- MUCH CAN BE DONE. CANNOT AFFORD TO BE DISHEARTENED BY PAST DIFFICULTIES
- ANSWERS TO ISSUES NOT YET CLEAR, BUT DATA AVAILABLE TO BATTLEFIELD COMMANDERS KEEP INCREASING
- WE MUST GO FORWARD – CANNOT EXPECT ENEMY TO STAND STILL
- OSD, JS, AND JFCOM SHOULD JOINTLY DEVELOP ROADMAP

DISCUSSION (continued)

The situation on the battlefield is not improving. It's getting worse. The amount of data available on the battlefield is growing rapidly, but the ability to turn it into information and knowledge useful to commanders is not keeping pace. If the time the warfighter spends examining the data isn't adequately compensated for by the increased knowledge he gains, then it may truly do him more harm than good. Perhaps the real mistake has been the failure to understand the enormous size of the problem and the fact that the problem keeps growing. That is, when all of this began, the problem was much simpler. As time has passed "we" have created an information explosion on the battlefield in an attempt to enable our military force to be dominant. We certainly cannot now abandon our warfighters as they attempt to use this abundance of information that we have provided for them.

On the other hand, some progress has been made in our attempts to deal with it. Perhaps the saving grace is that it is not only the military but also the entire world that is involved in the explosion of information. Furthermore, industry will provide many of the solutions.

Seventh, so press on we must for we cannot expect our future enemies to stand still, and we certainly do not want to have them waiting for us when we arrive.

To do this efficiently and effectively, a road map detailing the way forward must be developed. It appears that this would require a consolidated effort involving the warfighter to define the problems, and industry and academia to articulate the technology and develop the solutions. The effort might be lead by OSD and JFCOM.

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DEFENSE SEMINARS

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DEFENSE SEMINARS

Although this seminar was on intelligent agents, virtually no specific material was presented on the subject. The items presented were more along the lines of agents and the utility of solving problems with multi-agent teams.

The Commander's Edge team has already had individual meetings with a number of the speakers, the results of which are included elsewhere in this paper. Copies of the presentations are available at www.dtic.mil/dusdst/seminar.html.

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DEFENSE SEMINARS

Series: Defense Science & Technology Seminar On Emerging Technologies

Topic: Intelligent Agents - Software Assistants for the Warfighter

Sponsors: DUSD(S&T), DARPA and ONR

Date: May 12, 2000

Agenda:

- Welcome/Introduction
Dr. Delores Etter, DUSD(S&T)
Dr. Charlie Holland, ODUSD(S&T)
- Overview: Agents for the Warfighter
Dr. James Hendler, DARPA
- Problem Solving Agents
Dr. Suzanne Barber, U of Texas
- Agents and Information Assurance
Dr. Patrick Lincoln, SRI, Inc.
- Mobile Agents for the Military
Dr. Kenneth Whitebread, Lockheed Martin
- Decision Support for Command and Control
Dr. Jens Pohl, Cal Poly State

SCIENCE AND STUDY BOARDS

The team attended the following briefings. Members also met with the briefers and obtained briefing material as well as the indicated documentation (the speaker's current position is given):

Defense Science Board

- Briefing, "Commercial Technologies, Communications, and IT for Use by DOD," at IDA on 15 November by Mr. Donald Latham Staff VP, General Dynamics.
- Briefing, "Integrated Information Infrastructure," at IDA on 23 February 2000 by Dr. Michael Frankel VP, SRI International.
- Study Report, "Achieving Decision Superiority: The Integrated Information Infrastructure – A Vision for the 21st Century," 30 August 1999

Naval Studies Board

- Report, "Network-Centric Naval Forces, Overview," by the Committee on Network-Centric Naval Forces, 6 April 2000.

Air Force Science Advisory Board

- Briefing, "Joint Battlespace Infosphere," at IDA on 6 June 2000 by General James McCarthy USAF (Ret.), Professor, Air Force Academy and Director of the Institute for Information Technology Applications.

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SCIENCE AND STUDY BOARDS

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U.S. JOINT FORCES COMMAND

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U.S. JOINT FORCES COMMAND INTRODUCTION

During the visit to Joint Forces Command (JFCOM), staff officers did not mention any computer applications that are known to use intelligent agents to support the warfighter on the battlefield, although there were potential applications for such technology. The concerns of the staff were focused on solving "today's" problems, such as those one would expect to surface with staffs who are responsible for establishing requirements and for planning the use of technologies that support command and control of military forces. However, none of the conversations revealed that the staff was aware of the potential utility of intelligent agents. Specific areas of interest mentioned by the JFCOM staff are characterized in the following:

- Guaranteeing information assurance of data being passed between nodes of the joint forces involved, such as planning for and execution of military activities

- Expressing concern for interoperability of communications between Service elements within a joint task force
- Developing infrastructure for a Global Grid
- Maturing Precision Engagement concepts by improving collaboration between component forces
- Testing software for translating command guidance into a target list.

JFCOM recently initiated an effort at IDA to build an analyses tool to aid in analyses of data derived from the experiments the command conducts. This tool, the Analyst's Edge, does use intelligent agents to extract information deemed helpful to the operator from the myriad of data available on the simulated battlefield.

U.S. JOINT FORCE COMMAND

INTRODUCTION

- **PROJECTS**

- No specific projects were presented that use or plan to use intelligent agents in systems being developed that could aid the battlefield decision processes
- Analyst's Edge—a data analysis tool employing intelligent agents

- **PROBLEMS BEING ADDRESSED**

- Although not utilizing intelligent agents, JFCOM did describe an number of interesting battlefield problems on which they are working;
 - Information assurance
 - Interoperability between Services
 - Infrastructure to support a Global Grid
 - Precision Engagements with focus on collaboration
 - Converting Command Guidance into a JTF target list
- Analyses of the myriad of data derived from the experiments

U.S. JOINT FORCES COMMAND APPROACH

JFCOM is using two approaches to solve operational problems. One is a traditional approach used in DoD acquisition programs; the other uses experimentation and advanced development and testing of systems. In the first, a Capstone Requirements Document (CRD) supporting a World Wide Global Grid for communications is being prepared and staffed using a traditional approach to system acquisition.

The second involves JFCOM's role in experimentation and advanced concept testing. Experimentation is part of a DoD-wide effort to transform forces for use on future battlefields. JFCOM is at the center of DoD's experimentation efforts. This work is expected to result in changes to force employment concepts of all U.S. forces and rapid acquisition of promising technologies that could perform critical military tasks. One of the goals of joint concept development and experimentation is to harmonize Service capabilities and develop joint solutions for future joint force commanders.

One such experiment was J9901. It had a dual purpose: first, to begin learning how to employ experimentation to reach JFCOM objectives and then to examine a concept of attack operations in theater missile defense.

The JFCOM staff said the next major joint experiment is scheduled in August-September 2000 and is known as Millennium Challenge. It is an umbrella under which the uniformed Services will test new concepts and technology applicable to their specific Service needs.

Further, the JFCOM staff described three Advanced Concept Technology Demonstrations (ACTDs) in which JFCOM either is participating or has an interest. For example, JFCOM is involved

in an ACTD that is examining computer intrusion detection. Another ACTD falls in the area of Precision Engagement, which is sponsored by the Joint Staff. The test is designed to test methods of collaboration within a joint task force (JTF). Simply stated, the test will examine collaboration by geographically separated units through personal computers with a "white board" capability, much like a internet chat room. The white boards are intended to allow interactive planning and coordination between geographically separated units of a Service or JTF using both text and graphics. Finally, the last ACTD mentioned will attempt to develop software to translate command guidance into a JTF target list.

The Analyst's Edge is being developed by the Institute for Defense Analyses to support the Critical Mobile Targets Cell in the Air Operations experiments. This tool uses intelligent agent software among other things, to aid in identifying the sites TELs use to hide and to reload. It will be used to aid in investigating types of information that can help operators more quickly identify such things as TELs, missile transporters, depots, FOBs, and FOL and call for strikes against them.

The tool is designed to use data from the JFC experiments to provide a capability to perform post-experiment analyses and to operate in real-time in an ongoing experiment. It is designed to facilitate the testing of hypotheses as to what information better helps the battlefield operator. For example, how helpful would it be to color an object red if the probability of it being a TEL is 80 percent or greater? Sounds like a good idea. However, it could be that a well-trained team sees things that allow them to kill TELs before their probability reaches 80 percent and therefore better training is the key.

U.S. JOINT FORCES COMMAND APPROACH

- GLOBAL INFORMATION GRID CAPSTONE REQUIREMENTS DOCUMENT BEING PROCESSED
- EXPERIMENTATION & ADVANCED CONCEPT TECHNOLOGY DEVELOPMENT (ACTD)
 - Experimentation
 - J9901; proof of the experimentation concept
 - While examining attack operations in theater missile defense
 - Millennium Challenge
 - ACTDs with JFCOM interest
 - For improving network intrusion detection
 - Precision Engagement Concepts with a focus on collaboration during a JTF's targeting cycle
 - Using software to translate Command Guidance into a JTF Target List
- ANALYSES OF THE DATA AVAILABLE TO AND SUPPORT FOR THE CRITICAL MOBILE TARGETS CELL

U.S. JOINT FORCES COMMAND TYPES OF AGENTS USED

The Analyst's Edge project uses a number of agents, some intelligent and some not. Some agents take data from the experiment and place it in a database of known form, which is called warehousing. They then sift through warehoused data to find and annotate data that appear to be of interest. This is called data mining. These agents are not considered to be intelligent. Other agents examine the preprocessed data to locate such things as TEL hide and reload sites. They are considered to exhibit intelligence.

One might wonder what the difference is in the two sets of agents. In the first two, the functions preformed are rather straightforward. When a particular event occurs, the agent carries out a specific task. The third agent works with rather incomplete

sensor data. These data do not directly provide the location of hide or reload sites. For one thing, the data do not provide the size or shape of a site.

The agent must hypothesize that and be ready to change if better data arrives. That is, it has to build a data set, a memory of what appears to be relevant as data are arriving from the experiment (or being simulated to arrive as the tool runs the events in the same sequence as they occurred in the experiment). This data set needs to be revised as additional data arrives. The agents use arriving data along with their memorized data to generate hypothesis that can then be brought to an operator's attention. Thus, these agents deal with a great deal of uncertainty that is not present in the functions that the first two agents perform.

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U.S. JOINT FORCES COMMAND TYPES OF AGENTS USED

- THE ANALYST EDGE PROJECT UTILIZES:
 - Intelligent Agents
 - Non-intelligent Agents

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U.S. JOINT FORCES COMMAND STATUS, RESULTS, AND POTENTIAL BATTLEFIELD APPLICATIONS

The potential battlefield applications of a Global Grid, or netted communications paths, can be a most desirable technique to increase assurance of message arrival between military elements. While JFCOM's development of a CRD for Global Grid may appear to be only an administrative step, the document is crucial to defining JTF and component Service needs. One could speculate that future software agents used to solve some of the problems in infrastructure development will undoubtedly have elements of intelligence even though such agents have not matured in development, as of this review.

JFCOM has a facility for experimentation that permits both constructive and man-in-the-loop testing of concepts and systems. By using incremental development and testing, concepts and/or systems may be evaluated for further development. Perhaps slowly at first and then with an accelerated pace. The approach

has been referred to as spiral development: a management technique intended to allow one to economically proof concepts or test systems before deciding to integrate them into an existing weapon system or command and control system. Subsequent increases in a system's capability are included in a later version of the equipment and the spiral continues.

The ACTDs mentioned in an earlier slide are only those mentioned by the JFCOM staff during our discussions. Elements of the team are also aware of at least one additional ACTD, one on UAVs such as Global Hawk, that is closely monitored by other JFCOM staff elements. The ACTDs offer an opportunity to move technology more quickly to the user, but an ACTD may follow nonstandard acquisition processes to bring equipment into inventory earlier—a characteristic of which analysts need to be aware.

U.S. JOINT FORCES COMMAND

STATUS, RESULTS, AND POTENTIAL BATTLEFIELD APPLICATIONS

- **GLOBAL GRID**
 - Offers Communications Efficiencies
- **EXPERIMENTATION**
 - Uses crawl, walk, run testing environment
 - Permits Spiral Development in test of concepts and systems
- **ACTDs**
 - Permits rapid development of technology
 - Outside “standard” acquisition process
 - Can permit quick examination of concepts and systems

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U.S. JOINT FORCES COMMAND REFERENCES

Documents

None received

Meetings

Discussions, Staff Officers, US Joint Forces Command/J-6/J-3,
hosted by Commander Nancy King-Williams, USN,
January 6, 2000.

POCs

Commander Nancy King-Williams, USN JFCOM/J-634C (757)
836-0315. Email: kingwil@jfc.com.mil

Col. Moss, USAF J-6 Staff,

Lt. Col. Mansfield, USA. OPR for Global Information Grid
CRD

IDA Liaison—Mike Starry & Mason Brooks

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U.S. JOINT FORCES COMMAND REFERENCES

- DOCUMENTS
- MEETINGS
- POCs

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U.S. ARMY

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U.S. ARMY INTRODUCTION

The Army's goal has been to gain and maintain dominant strategic and tactical superiority. In the last several decades, electronic technology in the form of application-specific electronic devices and embedded digital technology were widely employed in the weapons systems. Lately, the microprocessor and related digital technologies have been revolutionizing not only weapons systems, but also the rest of the world as well. It is clear that digital technology has the power to provide Information Dominance on the battlefield, which will provide an enormous advantage to whomever can best leverage this technology.

Starting with an effort referred to as **Digitizing the Battlefield**, the Army had as its object the application of *information technologies* to acquire, exchange, and employ timely digital information throughout the battlespace, *tailored* to the needs of each commander, shooter, and supporter. This is to allow each of these to maintain the clear and *accurate vision* of the *battlespace* necessary to support both planning and execution.

This has evolved to the effort referred to as **Digitizing the Army**. This effort brings in the infrastructure that connects installations which support deployed forces. What is expected to emerge is a system of systems that interconnects Army elements from the highest level of command to the foxhole. This system will have the potential to provide information superiority on the battlefield. In other words, this system will be able to collect, process, and disseminate an uninterrupted flow of information that directly contributes to decision superiority at the command level—a key enabler in 21st century operations—while exploiting or denying an adversary's ability to do the same.

As good as such a system may be, any advantage lasts only until one's adversaries catch up or develop countermeasures. Thus, it would appear that the overall digitization effort will be a continuous process rather than one that reaches an end state.

U.S. ARMY INTRODUCTION

- **PROJECTS**
 - Digitizing the Battlefield
 - Digitizing the Army
- **PROBLEMS BEING ADDRESSED**
 - Maintaining Strategic and Tactical Superiority
 - Impact, global nature, and rate of change associated with Information Technology
 - The enormous advantage of Information Technology is available to those who employ it – including the enemy

U.S. ARMY APPROACH

During the 1970s and 1980s when the Army modernized, the focus was on the Big 5 systems, which include the M1 Abrams tank, the Patriot air defense system, and the Blackhawk helicopter. It was a platform-centric strategy. The new approach, called digitization, is intended to move the Army from the electronic technology era to the information technology era. It takes a more horizontal and network-centric approach to integrate the weapons and other battlefield systems with a cyber backbone. The strategy also extends from the digital computer network down to the platforms, vehicles, and selected soldiers. In the past, most of these were only provided with radios. Computers went predominantly to command centers.

Digitizing the Battlefield is an effort to link all of these resources together into a framework intended to provide a common picture of the battlefield and shared situational awareness across the force. All battlefield functional areas are included. The scope encompasses computers, radios, and

microprocessors employed by combat, combat support, and combat service support units. They are being linked together both vertically and horizontally with a Tactical Internet. The Army envisions that this program will not only continue to enhance individual weapons systems, but also will provide the digital framework to integrate the sensors, shooters, logistics, and commanders on the battlefield.

This effort has evolved into what is referred to as Digitizing the Army. This new effort includes the digital infrastructure that interconnects installations supporting deployed forces and that connects these installations with the deployed forces themselves. This approach will permit the Army to employ the best commercial practices and tools necessary to enable virtual meetings and collaboration among commanders, electronic commerce, paperless contracting, advanced inventory control, knowledge management, distance learning, and web-based operations Army-wide.

U.S. ARMY APPROACH

- **DIGITIZING THE BATTLEFIELD – MOVING FROM:**
 - Electronic Technology to Information Technology era
 - Platform Centric to Network Centric Warfare
 - Computer systems in Command Centers with Radios below to Interconnected Computers down to Individual Weapon Systems, Vehicles, and Selected Soldiers
- **DIGITIZING THE ARMY**
 - Includes digital infrastructure connecting installations supporting deployed forces and the deployed forces themselves

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U.S. ARMY TYPES OF AGENTS USED

The application of intelligent agents in the Army's command and control systems was not found in any of the briefings, meetings, or discussions relating to the Army's current or future plans. The Army does not "speak" in terms of "agents" as do other elements of DoD.

It may be simply that the Army started its digitization effort before the term "agent" came into vogue. At least it would appear that what some elements call "agents" the Army still refers to as software. On the other hand, there was no evidence that this software had any intelligence.

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U.S. ARMY TYPES OF AGENTS USED

- NONE REPORTED

U.S. ARMY STATUS, RESULTS, AND POTENTIAL BATTLEFIELD APPLICATIONS

Digitizing the battlefield has been a long effort for the Army. Programs to provide battlefield computer support for maneuver control, artillery, air defense, intelligence, and logistics were initiated in the '60s. The first of these, Tacfire, was fielded in the '70s. However, the outfitting of the individual battlefield elements (e.g., tanks, armored personnel carriers, etc.) with digital computers and connecting together has been quite a different experience. The Army has purchased a considerable amount of equipment to test the concept, and a significant number of exercises and operational tests have been conducted with various size units. However, in general, it appears that the results show no improvement in force lethality, survivability, or operational tempo when the units are equipped and interconnected with the digital equipment. Contributors to this

include the lack of sufficient connectivity, lack of maturity, lack of adequate techniques, tactics, and procedures (TTP), and inadequate collective unit training.

In theory this type of networking, with its potential to provide such things as a common operating picture, should permit the Army to gain and maintain a dominate strategic and tactical battlefield superiority. However, although the Army still has high hopes that its approach to digitization of the battlefield will provide these results, the result of testing is having an effect on fielding operational equipment. For example, the schedule set forth by the Chief of Staff of the Army called for the first Corps to be digitized by 1999. The current Campaign Plan now envisions the first digitized Corps by 2004.

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U.S. ARMY

STATUS, RESULTS, AND POTENTIAL BATTLEFIELD APPLICATIONS

- **ONGOING EFFORTS**
- **CURRENT STATUS**
- **FIELDING PROSPECTS**

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U.S. ARMY REFERENCES

Documents

Army Digitization: An Interview with LTG William H. Campbell, Army RD&A, November 1999.

Digitizing The Army, a briefing by LTG William H. Campbell.

Battlefield Digitization - A History, Draft Report, Mr. Robert C. Holcomb, IDA, July 2000.

Meetings, Briefings, and Demos

"Digitizing The Army," a briefing by LTG William H. Campbell, Director of Information Systems for Command, Control, Communications, and Computers, HQ, USA to IDA on September 22, 1999.

Meeting with Dr. Kenneth R. Whitebread, the Lockheed Martin program manager for the DARPA/Army DAIS effort on (for reference see <http://www.atl.external.lmco.com/projects/dais/> Note it may have been taken down). This effort is over and only involved non-intelligent agents.

POCs

LTG William H. Campbell, Director of Information Systems for Command, Control, Communications, and Computers, HQ, USA.

Dr. Kenneth R. Whitebread, Lockheed Martin program manager for the DARPA/Army DAIS Lockheed Martin Advanced Technology Laboratories, Camden, NJ (856) 338-4060 kwhitebread@atl.lmco.com.

Mr. Robert C. Holcomb, Operational Evaluation Division, IDA rholcomb@ida.org.

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U.S. ARMY REFERENCES

- DOCUMENTS
- MEETINGS, BRIEFINGS, AND DEMOS
- POCs

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U.S. NAVY

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U.S. NAVY FLEET BATTLE EXPERIMENTS

INTRODUCTION

The Navy has been supporting the testing of DARPA's Control of Agent Based Systems (CoABS) Grid (Agent Grid) in a series of Fleet Battle Exercises (FBX). The program, called Cooperative Agent for Specific Tasks (CAST), is supported by Lockheed Martin's Advanced Technology Laboratories (LMATL). The tests' objective is to examine the potential for independent agents to cooperate, using the Agent Grid approach, in real-world military situations. Although the program has explored the use of intelligent agents, none have been integrated into the real-time command and control system testing up to this point. (See the DARPA section for additional information on the DARPA program CAST.)

The Navy has already participated in three FBXs associated with DARPA's CAST project and is preparing for a fourth, each using the lessons learned from the previous experiments to refine the objectives and software for the next.

The most recent experiment was to address the movement of data between nodes in a battle group. Specifically, the problem being worked on was the movement of information applicable to diminishing the time needed to make a decision in the Time Critical Target (TCT) process.

The fourth FBX (Hotel) is to be conducted in August-September 2000.

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U.S. NAVY FLEET BATTLE EXPERIMENTS

INTRODUCTION

- **PROJECT**
 - Cooperative Agents for Specific Tasks (CAST)
- **PROBLEMS BEING ADDRESSED**
 - Movement of information between nodes of a Battle Group to assist in Time Critical Target (TCT) decision processes

U.S. NAVY APPROACH

A prototype of a desired system that would automatically transfer information between nodes was tested in FBX Delta. However, the intelligent agent application was tested as a stand-alone system and was not integrated into the FBX command and control network during the experiment.

FBX Echo used an agent-based application in real-time, but parallel to other systems in the experiment. The product from the intelligent agent application was then handed to an operator for use in identifying TCTs.

A similar situation existed in the Foxtrot experiment because the contractor had not made CAST compatible with all of the exercise systems.

The approach to testing of the CAST concept has thus far been incremental, apparently more by necessity than test design. Contractor interviews for the Navy's experiments indicated that project funding is rather low and man-hours available to devote to the project has limited the progress that can be made toward meeting test schedules. Consequently, each of the three completed FBXs may not have met the original expectation of the sponsor (DARPA).

In the first two trials, FBXs Delta and Echo, the objective was to search a mix of server sources, which contained manually written reports. These reports were searched for specific words which might suggest that the report contained indication and warning information. In the third experiment (FBX Foxtrot) the objective was to examine imagery annotations, produced by intel organizations, for information related to time critical targets. Information found was to be provided to those engaged in efforts to destroy time critical targets.

The next planned experiment may find CAST software agents performing less demanding tasks than was envisioned in earlier fleet experiments. Future experimentation with intelligent agents, in FBX Hotel, are expected to focus on finding specific information in databases to improve retrieval efficiency. For example, retrieval of imagery in disparate databases needed for mensuration in targeting processes. FBX Hotel, as noted above, will be run in late summer of CY 2000.

U.S. NAVY APPROACH

- **INCREMENTAL TESTING HAS BEEN CONDUCTED**
 - First experiment—a prototype effort
 - Second experiment—used off-line experimentation products
 - Third experiment
 - Run in real time and in parallel with other experimental applications and systems
 - Products were manually passed to man-in-the-loop operators for use in the FBX, i.e., no system-to-system interface
- **FOURTH EXPERIMENT WILL BE LESS AMBITIOUS THAN
ORIGINALLY ENVISIONED**
 - Agents will be used for retrieval of data from databases
 - Mensuration of target data is envisioned as goal

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U.S. NAVY TYPE OF AGENTS USED

- SEE THE COOPERATIVE AGENTS FOR SPECIFIC TASKS (CAST)
WRITE-UP IN DARPA SECTION

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U.S. NAVY STATUS, RESULTS, AND POTENTIAL BATTLEFIELD APPLICATIONS

CAST experiments continue with the FBX Hotel. But, the focus appears to be less ambitious, looking at applications that can aid a person by more efficiently locating and retrieving data. FBX Hotel will concentrate on the retrieval of imagery stored in a database for mensuration of nominated targets.

The contractor indicated that two stovepipes can or could be an obstruction to movement of agents across systems on which the agents reside. The first is legacy communications systems

that can obstruct free movements across communications nodes. The second obstruction could be the software itself. The contractor observes that there is a risk of agent applications themselves becoming stove-piped systems.

Once technology is proven, one could expect that the utility of intelligence data that can be moved across a communications network would be of immense benefit in presenting data needed for time-critical decisions.

U.S. NAVY STATUS, RESULTS, AND POTENTIAL BATTLEFIELD APPLICATIONS

- **ONGOING EFFORT**
- **CHANGE OF EXPERIMENT FOCUS**
- **TWO POTENTIAL STOVEPIPES**
 - Legacy communications systems
 - Software
- **POTENTIAL IN BATTLESPACE IS SIGNIFICANT**
 - Assumes unimpeded movement of data across nets
- **TIME CRITICAL TARGET DECISION PROCESS IS POTENTIAL AREA WHERE INTELLIGENT AGENTS COULD BE USEFUL**

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U.S. NAVY REFERENCES

Documents

Agent Systems in Command and Control Networks—Lessons Learned from Several Navy Fleet Battle Experiments, Dr. Kenneth R. Whitebread, et al. Undated.

“Agent Systems and the Grid in Command and Control Networks,” briefing by Dr. James Hendler, DARPA.

“Agent Systems and the Grid in Command and Control Networks,” briefing by Lockheed Martin.

Meetings

Discussion on *Experiences with Intelligent Agent Technology in Demonstrations and Experimentation* with Dr. Kenneth R. Whitebread, Lockheed Martin Advanced Technology Laboratories, 1 March 2000.

“Agent Systems and the Grid in Command and Control Networks,” briefing by Dr. James Hendler, DARPA, at IDA on 5 Jan 2000.

Discussion with Dr. James Hendler at DARPA on 21 December 1999.

POCs

Dr. James Hendler, ISO, DARPA jhendler@darpa.mil.

Dr. Kenneth R. Whitebread, Manager AT Programs, Lockheed Martin Advanced Technology Laboratories, Camden, NJ (856-338-4060) kwhitebread@alt.lmco.com.

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U.S. NAVY REFERENCES

- DOCUMENTS
- MEETINGS
- POCs

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U.S. MARINE CORPS

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U.S. MARINE CORPS INTRODUCTION

The Integrated Marine Multi-Agent Command and Control System (IMMACCS) is an experimental decision-support system developed by the CAD Research Center of the California Polytechnic State University for the U.S. Marine Corps Warfighting Laboratory. It was designed to be an integral component of experiments conceived by the U.S. Marine Corps to test emerging concepts in military command and control. The purpose of IMMACCS is to aid in the improvement of command and control tactics, techniques, and procedures (TTP) and in refining decision-making skills of individuals. It has been used in operational exercises since at least March 1999.

IMMACCS incorporates three fundamental concepts that distinguish it from existing command and control applications. First, it is a collaborative system in which computer-based agents

assist human operators by monitoring, analyzing, and reasoning about events in near real-time. Second, it includes an ontological (i.e., based upon that which exists) model of the battlespace that represents the behavioral characteristics and relationships among real-world entities such as friendly and enemy assets, infrastructure objects, and abstract notions. Third, IMMACCS provides no ready-made solutions that may not be applicable to the problem that will occur in the real world. Instead, the agents represent a set of tools that together with the human operator can adjust themselves to problem situations that cannot be predicted in advance. In this sense, the current IMMACCS is a first-generation example of an adaptive command and control system that has the potential to support planning, execution, and training functions concurrently.

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U.S. MARINE CORPS INTRODUCTION

- **PROJECT**
 - **IMMACCS**
- **PROBLEMS BEING ADDRESSED**
 - Improvement of C2 TTPs
 - Refinement of decision-making skills of individuals

U.S. MARINE CORPS APPROACH

IMMACCS uses the Integrated Collaborative Decision Model (ICDM) architecture, developed by the CAD Research Center, as an underlying framework for coordinating the activities of multiple computer-based agents and human operators. The approach emphasizes cooperation and communication among many agents rather than intelligence and learning of individual agents.

IMMACCS uses an object-based representation of information. That is, information processed within the system is described as objects having attributes, behavior, and relationships to other objects.

IMMACCS is based on a three-tier architecture that has separate tiers for information (storage), logic (agents), and presentation (users). This arrangement is intended to allow multiple human decision-makers to solve complex problems in a collaborative fashion while obtaining decision-support assistance from a collection of heterogeneous on-line agents.

IMMACCS uses SharedNet, developed by the Jet Propulsion Laboratory, to interconnect the agents. SharedNet allows users to subscribe to information as well as to send queries. Information subscribed to is automatically pushed to the subscriber as soon

as it is available. Queries allow users to pull information as it is needed. While this simplifies communications to some degree, it can become a scaling bottleneck. For example, in the Urban Warrior Advanced Warfighting Experiment in March, 1999, "the SharedNet was able to handle a small number of clients (i.e., 10 to 20) and support a sustained transaction rate of 60 to 70 object updates per second.... The SharedNet must be scalable to support a much larger number of clients (i.e., 100 to 200) and a larger transaction rate (i.e., hundreds of updates per second). Currently the Common Object Request Broker Architecture (CORBA) and the object-oriented database that provides persistence to the Object Instance Store (OIS), are significant processing bottlenecks.... It is likely that more efficient methods of providing persistence to the OIS, will need to be investigated." OIS is the primary object factory and repository for the SharedNet, which manages the object creation, deletion, and modification of object attributes.

The IMMACCS contains the capability to record and playback, in real or simulated time, event sequences to support evaluations and training.

U.S. MARINE CORPS APPROACH

- **EMPHASIS ON COOPERATION AND COMMUNICATION AMONG MANY AGENTS**
- **OBJECT-BASED REPRESENTATION OF INFORMATION**
- **THREE-TIER ARCHITECTURE; INFORMATION, LOGIC, AND PRESENTATION**
- **SHAREDNET TO INTERCONNECT THE AGENTS**
- **RECORD AND PLAYBACK, IN REAL OR SIMULATED TIME, EVENT SEQUENCES**

U.S. MARINE CORPS TYPES OF AGENTS USED

Logistics Agent—Monitors general readiness of friendly forces, e.g., fuel and water.

Fires Agent—Responds to call for fire (CFF) requests. Selects the best weapon that is available, etc.

Engagement Agent—Monitors incidents of friendly units subjected to enemy fire and provides alerts with associated position information.

Blue-On-Blue Agent—Monitors the presence of friendly forces on or near a Fire Event of a CFF target and generates alerts.

Intel Agent—Monitors the detection of hostile sensors, e.g., radar installations, and the automatic generation of a CFF on this potential target.

Hazard (NBC) Agent—Monitors battlespace for indications of atmospheric and climatic events that are considered to be hazardous.

ROE Agent—Monitors actions for violations of Rules of Engagement (ROE), e.g., targeting a hospital (but doesn't say from where this type of knowledge about the targets comes).

General Sentinel Agent—Monitors and provides alerts on simple conditions, e.g., the detection of enemy units and hostile civilian entities within a specified distance of any operator-specified position (but doesn't say from where this type of knowledge about the targets comes).

EUT Sentinel Agent—Automatically created for each End-User Terminal (EUT) and alerts the EUT operator if either an enemy unit moves to within 300 meters of the current position of the EUT operator, or if a CFF includes a target that is within 300 meters of the current position of the EUT operator.

Decision Point Agents—Acts on user requests to be notified is certain events occur (e.g., enemy force reaches a specified road).

U.S. MARINE CORPS TYPES OF AGENTS USED

- **LOGISTICS**
- **FIRES**
- **ENGAGEMENT**
- **BLUE-ON-BLUE**
- **INTEL AGENT**
- **HAZARD (NBC)**
- **ROE**
- **GENERAL SENTINEL**
- **EUT SENTINEL**
- **DECISION POINT**

U.S. MARINE CORPS REFERENCES

Documents

IMMACCS A Multi-Agent Decision-Support System Design
Institute Report: CADRU-12-99, August 1999, CAD Research Center, College of Architecture and Environmental Design, California Polytechnic State University, San Luis Obispo, CA.

IMMACCS Integrated Marine Multi-Agent Command and Control System, Common View of the Battlespace at any access node, color brochure, CAD Research Center, California Polytechnic State University San Luis Obispo, CA.

CADRC Currents, March 2000 Newsletter, CAD Research Center, California Polytechnic State University San Luis Obispo, CA.

Meetings, Briefings and Demos

"Collaborative, Distributed, Multi-Agent Decision-Support Systems in support of Joint Warfighting and Synthetic Theater Of War (STOW)," briefing by Professor Jens Pohl, Executive Director, CAD Research Center to IDA/JAWP on January 24, 2000.

IMMACCS Demo, CAD Research Center and Marine Corps Warfighting Laboratory, January 24, 2000.

POCs

Professor Jens Pohl, Executive Director, CAD Research Center, California Polytechnic State University San Luis Obispo, CA (805) 756-2841, emailjpohl@calpoly.edu).

Col Ray Schmittal, USMC, Marine Corps Warfighting Laboratory, Quantico, VA.

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U.S. MARINE CORPS REFERENCES

- **DOCUMENTS**
- **MEETINGS, BRIEFINGS, AND DEMOS**
- **POCs**

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U.S. AIR FORCE

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U.S. AIR FORCE INTRODUCTION—GENERAL

Four levels of activity in the Air Force were contacted. First, the team attended a briefing by LtGen William Donohue, Director, Communications and Information, HQ, USAF on "Information Technology—IT's Impact on Air Force Mission and Business Processes." This was followed by a meeting with him and his staff. Then, with his support, the team contacted the Air Force's Aerospace Command and Control and Intelligence, Sensor and Reconnaissance Center (AC2&ISRC) at Langley Air Force Base, VA. Discussions there lead to the Electronic Systems Center at Hanscom AFB, MA, and the Air Force Research Laboratory's Information Directorate (AFRL/IF) at Rome, NY.

Three offices at Langley were visited: two under the Center and one that is part of ACC's Directorate of Operations. At

AC2&ISRC, the Center's Technical Advisor provided briefings and discussions on plans to incorporate both technical and procedural improvements to Air Force C². The other AC2&ISRC offices' presentations focused on procedural processes within an Air Operations Center. The meeting with the ACC Director of Operations Staff was on the use of intelligent agents in battle management. Subsequent telephone contact was made with the AC2&ISRC's staff officer responsible for TCT systems within the Air Force's command and control system.

Details of each of the major contacts are provided in the following.

U.S. AIR FORCE

INTRODUCTION—GENERAL

- **FOUR LEVELS OF AIR FORCE ACTIVITY CONTACTED**
 - Headquarters
 - Headquarters USAF
 - Director of Communications and Information
 - Headquarters Air Combat Command
 - Command and Control Division, Director of Operations
 - Centers
 - AC2&ISR Center
 - Office of the Technical Director
 - Information Processes Interoperability and Exploitation Division
 - Theater Missile Defense Branch
 - Electronic Systems Center
 - Office of the Director, Integrated Command and Control Program Office
 - Laboratory
 - Air Force Research Laboratory
 - Information Directorate (Rome, NY)

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INTRODUCTION AT HEADQUARTERS USAF

LtGen William Donahue, Director of Communications and Information (AF/SC), Headquarters United States Air Force, has briefed the Air Force's senior leadership championing funding of programs that would move the Air Force toward web-based communications and information systems.

Such a move could overcome several operational and technical challenges that the Air Force faces in its support of deployed forces. A possibility exists, in the future, that deployed Air Force elements could be based at geographically dispersed

locations, requiring development of better ways to maintain communications—not only between sister Air Force units but also with all echelons of the deployed force, which could be a joint task force. The deployed Air Force units may be sparsely manned which will require better methods of gathering, processing, and displaying information. Thus, technology, such as intelligent software agents that could aid management of data and communications, would be a benefit if not a necessity for Air Force units at many levels.

INTRODUCTION – AT HEADQUARTERS U.S. AIR FORCE

- **PROJECT**

- Moving the Air Force to a web-based information system
- Air Force Director of Communications and Information has advocated needed changes

- **PROBLEMS**

- Supporting deployed forces using light and lean expeditionary force concepts
- Effectively communicating, informing, and managing dispersed Aerospace Expeditionary Force (AEF) elements during deployment
- Finding technology that can be used for enhancing displays, and the processing and retrieval of data needed to assist expeditionary forces, regardless of force size

INTRODUCTION

USAF AEROSPACE COMMAND AND CONTROL & INTELLIGENCE, SENSORS & RECONNAISSANCE CENTER (AC2&ISR)

The AC2&ISR Center has the responsibility to "fix" Air Force communications. Experiments are being conducted to help solve problems that the Air Force has identified and also to help prove new concepts of operations. The Air Force's joint experimentation program, known as Joint Expeditionary Force Experiment (JEFX) has scheduled its next experiment in August-September of CY 2000. The Air Force's experiments are guided by a concept adopted from a 1998 Air Force Scientific Advisory Board study. The concept, Joint Battlespace Infosphere, describes both a concept of operations and the aerospace environment in which the Air Force may fight (see reference *Building the Joint Battlespace Infosphere*).

The year 2000 JEFX experiments have been labeled the Joint Battlespace Infosphere Wright Flyer (JBIwf). Just as the Wright brothers took the first incremental steps in developing the flying machine, the Center is taking its first tentative steps in developing a C2&ISR structure for future Air Force Expeditionary operations. JEFX-00 will concentrate on an integrated ISR Battle Management (ISRBM) thread to illustrate the benefits of the JBI as it applies to Joint Vision 2010.

One will note the three problems listed are focused on supporting forces that may be deployed to dispersed sites, must fight in joint or coalition forces, and need to make decisions more rapidly than the adversary it faces.

INTRODUCTION

USAF AEROSPACE COMMAND AND CONTROL & INTELLIGENCE, SENSORS & RECONNAISSANCE CENTER

- **PROJECT**
 - Joint Battlespace Infosphere Wright Flyer (JBIWF)
 - Joint Expeditionary Force Experiment (JEFX-00)
- **PROBLEM**
 - Rapidly and effectively assemble disparate forces and resources into a joint tailored force to deploy anywhere in the world
 - Develop a system of systems that integrates, aggregates, and distributes information to users at all echelons, from the command center to the battlefield
 - Interpret information and make decisions faster than the adversary, thereby ensuring decision superiority

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INTRODUCTION
AIR FORCE AEROSPACE RESEARCH LABORATORY INFORMATION DIRECTORATE

The project manager of the agent-related DARPA-sponsored projects at the AFRL/IF indicated that AFRL is working with DARPA on agent-based research. AFRL/IF has four programs that are exploring agent research, which could lead to use of intelligent agents in military systems.

DARPA-sponsored projects that the AFRL/IF is monitoring are shown on the facing page. Details of these projects can be found in the DARPA section. The Air Force's Office of Scientific Research and Electronic Systems Center did not reveal any additional programs where intelligent agents were known to exist.

INTRODUCTION

AIR FORCE RESEARCH LABORATORY INFORMATION DIRECTORATE

- **PROJECTS**

- Control of Agent Based Systems (CoABS)
- DARPA Agent Markup Language (DAML)
- Taskable Agent Software Kit (TASK)
- Autonomous Negotiating Team (ANTS)

- **PROBLEMS BEING ADDRESSED**

- Control of large systems of autonomous software agents
- Enable software to dynamically identify and understand information sources and to provide interoperability between agents in a semantic manner
- Extend the current scientific and mathematical foundations of agent-based computing
- Distributed allocation problems

U.S. AIR FORCE APPROACH

The Air Force's Director for Communications and Information presented a compelling argument to the Air Force's senior leadership at a semi-annual conference held in June 1999. The argument was for migration of the Air Force to a web-based communications systems. One goal is to "tie" all Service components together in a grid that could give many advantages, among them, better support for and by deployed air elements such as the Air Force's lighter, rapidly deployable Aerospace Expeditionary Force (AEF).

The AC2&ISR Center has developed a strategy and prioritized programs that support fundamental technologies and processes that are needed to improve Air Force Information technology at the unit level, system level, and joint/coalition operations. The Center has a recommended investment plan to

support the strategies. And, both new systems and processes are being evaluated in various experimentation tests. All systems and processes being examined are essentially focused on improving the rapidity with which time critical decisions can be made.

While the Center is working on "fixing" the Air Force's communications problems, DARPA may be the best source of advocacy for software technologies associated with intelligent agents at this point in time. For it is DARPA that is funding four agent-based research projects crucial to the Air Force's future in Information Technology. But, the information made available to the team indicates that none of the systems being considered for inclusion in AC2&ISR Center's experimentation possess intelligent agents.

U.S. AIR FORCE APPROACH

- AIR FORCE SEES A NEED FOR AND IS MAPPING A PATH TOWARD WEB-BASED INFORMATION TECHNOLOGY SYSTEMS
 - Recognizes the importance of Information Technology impact on Air Force mission and business processes
 - Aerospace Expeditionary Forces need more efficient Information Technology solutions
- AC2&ISR CENTER IS ADVOCATE FOR PLANNING THE “WAY AHEAD” FOR MORE EFFICIENT COMMAND AND CONTROL THROUGH INFORMATION TECHNOLOGY
- ADVANCED RESEARCH, THROUGH DARPA SUPPORT, IS PURSUING TECHNOLOGIES NEEDED TO OBTAIN AGENT-BASED SOLUTIONS
- NONE OF THE SYSTEMS BEING CONSIDERED FOR INCLUSION IN AC2&ISR CENTER’S NEAR-TERM EXPERIMENTATION POSSESS INTELLIGENT AGENTS

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U.S. AIR FORCE TYPES OF AGENTS USED

- **SEE THE DARPA SECTION FOR THE TYPE OF AGENTS USED IN:**
 - Control of Agent Based Systems (CoABS)
 - DARPA Agent Markup Language (DAML)
 - Taskable Agent Software Kit (TASK)
 - Autonomous Negotiating Team (ANTS)

U.S. AIR FORCE STATUS, RESULTS, AND POTENTIAL BATTLEFIELD APPLICATIONS

The Air Force continues experimentation and systems tests, with a goal of decreasing the time required to make time critical decisions.

For example, the next Air Force JEFX (August-September 2000) will include systems whose goal is to reduce the time required to make decisions associated with time critical targets. One such system, which is designed to help pair strike platforms (airborne or ground based) with targets, is known as the Attack Operation Decision Aid (AODA). Another system, which performs a similar task for the Air Operations Center's intelligence cell, is the Time Critical Target Analysis (TCTA) console, which helps perform target data mining and correlation.

Another system performs Automated Assistance for Initial Preparation of the Battlefield (A2IPB). Yet another is the Enhanced Early Warning (E2W) for TBM track correlation. It can be used to enhance chemical-biological effects predictions in the projected missile impact zones.

Each of the above systems contribute to the management of forces and weapons systems, and all require access to and processing of relatively large volumes of data. Yet none possess intelligent agents that could potentially improve the rapidity with which data are processed. This could free the analysts from having to invest time in manual processes and shorten the time critical target decision processes.

U.S. AIR FORCE

STATUS, RESULTS, AND POTENTIAL BATTLEFIELD APPLICATIONS

- **MODERN BATTLEFIELD OPERATIONS AFFIRM A NEED FOR IMPROVEMENTS THAT MUST BE ACHIEVED BY TIME CRITICAL TARGET (TCT) DECISION PROCESSES AND SYSTEMS IN ARMED FORCES COMMAND AND CONTROL FACILITIES**
- **BOTH SYSTEMS AND PROCESSES CONTINUE TO BE TESTED TO ATTAIN IMPROVEMENTS FOR TIME CRITICAL DECISIONS THAT CAN BE MADE QUICKER THAN AN ADVERSARY**
 - Some current systems include: Attack Operations Decision Aid (AODA); Time Critical Target Analysis (TCTA); Automated Assistance with Intelligence Preparation of the Battlefield (A2IPB), and Chemical-Biological Assessment (E2W)
 - Processes include attempts at more efficient information handling; to be tested with man-in-the-loop experimentation
 - Both systems and processes can require handling large volumes of data from various sensors and databases
- **SOLUTIONS THAT MAY GUARANTEE AN ADVANTAGE IN TCT DECISION TIME HAVE NOT YET BEEN DEVELOPED**

U.S. AIR FORCE REFERENCES

Documents

- "Building the Joint Battlespace Infosphere," briefing on 1999 USAF Scientific Advisory Board study, Gen James P. McCarthy USAF (Ret.) Chairman.
- "Information Technology's Impact on Air Force Mission and Business Processes," LtGen. William Donahue, USAF, Director, Communications and Information, HQ United States Air Force.
- "Command and Program Overview," briefings by Mr. Gary Barringer, Technical Advisor to the Commander, AC2&ISR Center, Langley AFB, VA, 7 Jan. 2000.
- "Multi-Source Information Control Officer. (A Concept for Evaluation)," briefing by LtCol David Bell, AC2&ISR Center, 7 Jan. 2000.

Meetings, Briefings, and Demos

- "Building the Joint Battlespace Infosphere," briefing to IDA research staff by Gen James P. McCarthy USAF (Ret.), Olin Professor of National Security, U.S. Air Force Academy, 6 June 2000.
- "Information Technology's Impact on Air Force Mission and Business Processes," briefing to the IDA research staff by LtGen William Donahue, USAF, Director, Communications and Information, HQ United States Air Force, 22 October, 1999.
- Discussion, LtGen William Donahue, USAF, Director, Communications and Information, HQ United States Air Force, 9 Dec. 1999, Pentagon, Washington, DC.
- "Command and Program Overview," discussions and briefings, Mr. Gary Barringer, Technical Advisor to the Commander, AC2&ISR Center, Langley AFB, VA, 7 Jan. 2000.

"Multi-Source Information Control Officer. (A Concept for Evaluation)," discussion and briefings, LtCol David Bell, AC2&ISR Center, 7 Jan. 2000.

"Discussion of Time Critical Processes and Equipment Used in an Air Operations Center," discussions, Col Robert Wooley and staff, ACC/ XOY, ACC Directorate of Operations, 8 Feb. 2000.

"EAF On-Line," briefing by LtGen William Donahue, USAF, Director, Communications and Information, HQ United States Air Force, 15 June 1999.

"Information Technology—IT's Impact on Air Force Mission and Business Processes," briefing by LtGen William Donahue, USAF Director, Communications and Information, HQ United States Air Force, at Institute for Defense Analyses, 22 October 1999.

- Advocacy briefing for web-based solutions to future Air Force Information Technology needs.

"TBMCS—The Way Ahead," briefing 18 Nov. 1999, Aerospace Command and Control and Intelligence, Sensor and Reconnaissance Center (AC2&ISRC), Langley AFB, VA, on 7 Jan 2000.

- Defines problems, technical approach, and investment strategies to attain foundation for answering future Air Force operations.

"Joint Battlespace Infosphere, Wright Flyer Initiative Proposal," briefing (AC2&ISRC), Langley AFB, VA, on 7 Jan, 2000.

- A process initiative: Multi-source Information Control Officer (MICO).

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U.S. AIR FORCE REFERENCES

- DOCUMENTS
- MEETINGS, BRIEFINGS, AND DEMOS
- POCs

U.S. AIR FORCE REFERENCES (continued)

"Expeditionary Force Experiment," briefing EFX SPO, Langley AFB, VA, undated.

"Joint Integrated TCT Cell," briefing by LtCol David Jones, Aerospace Command and Control and Intelligence, Sensor and Reconnaissance Center (C2NT), Langley AFB, VA, undated.

- A concept for theater missile defense.

"Agent Based Computing," presentation and discussion by Professor Jim Hendler, Information Systems Office, Defense Advanced Research Agency, at Institute for Defense Analyses, 5 Jan 2000.

- A concept and evaluation of intelligent agents in time critical target processes.

POC

US Air Force Scientific Advisory Board

- Gen James P. McCarthy USAF (Ret.), Olin Professor of National Security and Director of the Institute for Information Technology Applications, US Air Force Academy (719) 333-2746 Jim.McCarthy @ USAFA. AF. Mil.

HQ USAF

- Office of the Director, Communications and Information (AF/SC), LtGen William Donahue: (703) 695-6324.
- AF/SC Commander's Action Group (AFCIC/CCG); (703) 588-6321/-6313/-6320.

- Mr. David Hangsleben, LtCol Michael German
(Located at 1500 Wilson Blvd., Rosslyn, VA).

AC2&ISR Center, Langley AFB, VA.

- Office of Technical Advisor to the Center---Mr. Gary Barringer (AC2ISRC/CCT).
 - Executive to Technical Advisor. Comm. (757) 764-0751; DSN 574-0751; FAX x3373 (Maj. Jervey).
 - Theater Missile Defense Branch. (757) 2254-0259 (LtCol Jones, Maj. Tony Romano, Mr. Sheppard).
- Electronic Systems Center, Hanscom AFB, MA.
- Integrated Command and Control System Program Office DSN 478-8248 / 2389.

- Director Brig. Gen. Edward L. Mahan.

Air Force Research Laboratory, Information Directorate, Rome New York.

- James Lawton, program monitor for intelligent agents projects; Comm. (315) 330-4476; DSN 587-4476; email james.lawton@rl.af.mil.

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DARPA

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DARPA INTRODUCTION

The Defense Advanced Research Projects Agency (DARPA) is the central research and development organization for DoD. It manages and directs selected basic and applied research and development projects for DoD and pursues research and technology where risk and payoff are both very high and where success may provide dramatic advances for traditional military roles and missions and dual-use applications. More information can be found on DARPA's website at <http://dtsn.darpa.mil/>.

"The Information Systems Office (ISO) mission focuses on revolutionizing national security and military operations through the power of information systems technology...to know, to know more, to know faster, and be able to act flexibly." More information can be found on the ISO website at <http://dtsn.darpa.mil/iso/>.

DARPA INTRODUCTION

- **DOD R&D ORGANIZATION**
- **BASIC AND APPLIED RESEARCH**
- **WHERE**
 - Risk and payoff very high
 - Results may provide dramatic advances for military
- **INFORMATION SYSTEMS OFFICE**
 - Focus on power of information systems technology
 - Agent-based techniques

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DARPA

INTRODUCTION (continued)

- WITHIN THE INFORMATION SYSTEMS OFFICE FOUR PROJECTS RELATE TO DEVELOPMENT OF AGENT-BASED TECHNIQUES:
 - Control of Agent-Based Systems (CoABS)
 - DARPA Agent Markup Language (DAML)
 - Taskable Agent Software Kit (TASK)
 - Agent Negotiated Tasks (ANTS)
- THE PROJECTS ARE ADMINISTERED BY PROFESSOR JIM HENDLER. THEY ARE DESCRIBED IN SOME DETAIL IN THE FOLLOWING. MORE INFORMATION CAN BE FOUND ON THE ISO WEBSITE AT <http://dtsn.darpa.mil/iso/index2.asp?mode=9>

DARPA APPROACH

Control of Agent-Based Systems (CoABS)

This program goal is to develop and demonstrate techniques to safely control, coordinate, and manage large systems of autonomous software agents. The CoABS program will develop and evaluate a wide variety of alternative agent control and coordination strategies to determine the most effective strategies for achieving the benefits of agent-based systems, while assuring that self-organizing agent systems will maintain acceptable performance and security protections.

Some of the elements of the CoABS project are being tested in the Navy's Fleet Battle Experiments. See the Navy section for more information.

DARPA Agent Mark Up Language (DAML)

The goal of the DAML program is to create technologies that will enable software agents to dynamically identify and understand information sources and to provide interoperability between agents in a semantic manner. This goal will be pursued by a research plan that includes the following six tasks:

1. Create an Agent Mark-Up Language (DAML) built upon XML that allows users to provide machine-readable semantic annotations for specific communities of interest.
2. Create tools that embed DAML markup onto web pages and other information sources in a manner that is transparent and beneficial to the users.
3. Use these tools to build up, instantiate, operate, and test sets of agent-based programs that markup and use DAML.

4. Measure, via empirical experimentation, the productivity improvements provided by these tools.

5. Apply these tools to third-party agent development, military-specific problems, and support for the intelligence community so as to evolve DAML technologies towards large-scale use.

6. Transition DAML to the commercial and military markets via partnerships with industrial and defense-related (C2 and intelligence) organizations.

Taskable Agent Software Kit (TASK)

The TASK program will extend the current scientific and mathematical foundations of agent-based computing with the goal of adding rigor to engineering of agent-based systems. In particular TASK will develop mathematically correct techniques for modeling and analyzing agent behaviors, agent design methods, and the design of agent creation tools. Using these models, TASK will compare the performance of competing agent-creation approaches to test agent behaviors with respect to mathematically validated domain models. Key research goals include:

1. Agent Behavior Models—Develop methods for modeling the behavior of agents operating in dynamic, and possibly chaotic, networking environments.
2. Robust Agent Behaviors—Apply stochastic and/or heuristic-based optimization methods as a basis for achieving robust agent performance in the context of such uncertain environments.

DARPA APPROACH

- CONTROL, COORDINATION, AND MANAGEMENT OF LARGE SYSTEMS OF AUTONOMOUS SOFTWARE AGENTS (CoABS)
- LANGUAGE TO FACILITATE AGENT INTEROPERABILITY (DALM)
- AGENT MODELING AND ANALYSES TECHNIQUES (TASK)
- AGENT NEGOTIATIONS (ANTS)

DARPA APPROACH (continued)

Taskable Agent Software Kit (TASK) (continued)

3. Modeling Agent Systems—Model critical scalability, stability, and dynamic performance surfaces for developing large-scale agent systems.
4. Agent Creation Tools—Based upon the principles discovered in the preceding tasks, develop Agent Creation Toolkits to allow agents techniques to be utilized by non-agent literate, subject domain experts.

Agent Negotiated Tasks (ANTS)

This project is intended to explore ways to use highly decentralized and autonomous negotiation tasks, roles, and allocations by software agents to provide solutions that are good enough and timely enough for their intended purpose by gaining access to data as well as sharing data with peer and other echelons of agents.

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DARPA TYPE OF AGENTS USED

The team's understanding is that in previous years DARPA was engaged in work on intelligent agents. Lately, the emphasis of their work seems to have shifted more toward the control, coordination, and management of large systems of autonomous agents. These autonomous agents may or may not be intelligent. In the Fleet Battle Experiments being done with the U.S. Navy, the team was told that no intelligent agents were involved (see the Navy section). However, this does not mean that a system of

agents as a whole does not exhibit intelligence. This would certainly be true of systems that are given a large degree of control in their ability to self-organize. But, this point was never made as part of these discussions or any other discussions of the application of multiple autonomous agents. On the other hand, it would seem that the agents involved in the ANTS project would potentially exhibit intelligence if they are able to negotiate at a level beyond that of a fixed set of rigid rules.

DARPA
TYPE OF AGENTS USED

- **INTELLIGENT AGENTS**
- **MULTIPLE AUTONOMOUS AGENTS**
- **SELF-ORGANIZING SYSTEMS**
- **AGENTS THAT CAN NEGOTIATE**

DARPA STATUS, RESULTS, AND POTENTIAL BATTLEFIELD APPLICATIONS

In a crisis, military commanders and their supporting staff officers must make hundreds of decisions quickly. The quality of their decisions and the subsequent actions dictate political outcomes with great significance to national defense. Although the number and availability of information sources are increasing, current military command and control systems require vast amounts of manual manipulation and user-specification of all details.

To increase the military user's productivity and, by extension, our military capability, the next generation of software called "Software Agents" is being developed to automatically accept abstract tasking, obtain needed information, decide how to solve simple problems, help the user solve difficult problems, and take action on the user's behalf. However, it must be assured that the agent-based systems cannot mitigate dangerous and chaotic behaviors such as unnecessary resource consumption, faulty communication, poor performance, system shutdowns, or security vulnerabilities.

For example, the CoABS program seeks to develop and evaluate control strategies that will allow military commanders

and planners to automate relevant command and control functions such as information gathering and filtering, mission planning and execution monitoring, and information system protection. Through the effective control of agent systems, the intelligent agents need to work in harmony to significantly strengthen military capability by reducing planning time, automating and protecting C2 functions, and enhancing decision-making.

The DAML program seeks to provide flexible tools for military software development and use information gathering by allowing agents to use DAML/ontology for search. It provides software development enabling algorithms/code fractions that advertise critical properties. The coupling of legacy systems where "agentization" of systems is enabled through grid interoperability mechanisms would advertise their capabilities in DAML.

Military systems tend to be very complex and, therefore, the value of applying agents to those systems is difficult to validate. The TASK project seeks to aid these assessments.

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DARPA REFERENCES

Documents

"Control of Agent-Based Systems," briefing by Dr. James Hendler, DARPA, March 1999.

"Agent-Based Computing," briefing by Dr. James Hendler, DARPA, 5 January 2000.

Meetings

"Agent Systems and the Grid in Command and Control Networks," briefing by Dr. James Hendler, DARPA, at IDA on 5 Jan 2000.

Discussion with Dr. James Hendler at DARPA on 21 December 1999.

POCs

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DARPA REFERENCES

- DOCUMENTS
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SANDIA NATIONAL LABORATORY

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SANDIA INTRODUCTION

Several groups at Sandia are conducting research on intelligent agents. For example, investigation into multi-agent systems and the various mechanisms of team formation, such as collective behavior and swarming algorithms that must come into play with multi-agent systems is ongoing. They are also working on agent communication languages, agent-based evolutionary computing methods for decision support, and agent-based enterprise integration tools. These approaches do not assume the existence of a single master "controller" governing the fleet, because such an entity is considered to present a single point of failure. Instead, they focus entirely on decentralized control to make the collective robust. They are developing a standardized architecture in which agents can be purely software, purely hardware (robots), or a hybrid collective consisting of both

working in tandem. Two of these projects are discussed here: cybersecurity and swarming algorithms for agents/robots. Additional information can be found at the following websites:

Sandia Labs

(<http://www.sandia.gov/media/NewsRel/NR2000/agent.htm>),

Albuquerque Journal

(<http://www.abqjournal.com/scitech/42699scitech05-27-0.htm>),

Beyond2000

(http://www.beyond2000.com/news/story_652.html),

Agent technology for robots

(http://www.bbc.co.uk/tw/stories/technology/0004_robots.shtml).

SANDIA INTRODUCTION

PROJECTS/PROBLEMS BEING ADDRESSED

- **CYBERSECURITY**

- Robust protection against attack for systems connected to the Internet

- **SWARMING ALGORITHMS FOR AGENTS/ROBOTS**

- Difficulties associated with deploying individual agents

SANDIA APPROACH

Cybersecurity

Sandia's approach is to develop an agent-based security system that will be able to maintain continuous vigilance for inappropriate activity and, when such activity is noted, to be able to evoke suitable measures to counter the activity before it can do any harm to the system being guarded. That is, the approach is to develop a smart security system, in part known as cyberagents, designed to learn from its environment rather than simply respond to pre-programmed threats.

The agents run on multiple computers in a network. They can act alone or together as a single, distributed program. The agents across the network constantly compare notes to determine if any unusual requests or commands have been received from external as well as internal sources. The agents are designed to detect and deal with subtle as well as obvious attacks and to gather information on things such as port scans, faint probes, attempted installation of Trojan horses, and denial of service attacks.

The concern is not so much with the teenage hacker but with more serious affects from foreign governments or corporations who may take a long time, very gently probing to find computers that they can take over or compromise. An example is cracking a privacy code intended to protect financial, medical, or other critical data.

One thing that distinguishes the Sandia agent programs from others is that they integrate security functions with normal services—"ftp," "WWW," and browsers. They're all in each agent. This provides intrinsic security to each user.

No central authority operates the agent. Instead, decentralized control makes each agent autonomous, yet cooperative. This is to prevent a single point of attack that can bring down the collective. The multiagent program can also send out probes to locate and assess its attacker.

Robots

In this case, the agents are physical robots, although the technology may be applicable to non-physical robots as well. Sandia's perception here is that complex robots can be unreliable because many component parts can potentially fail. So they have set out to design a swarm of simple, cheap robots to overcome their lack of intelligence by working together. That is, although each individual robot may not be very smart, when they work together by sharing information about what each has found and where, they will overcome their lack of intelligence.

SANDIA APPROACH

CYBERSECURITY

- **CURRENT APPROACHES ALWAYS BEHIND – OFTEN TOO LATE**
- **NEED GUARDS WHICH CAN**
 - “Sense” inappropriate activity and are able to take corrective action
 - Notify cooperating software in other computers
 - Learn from their environment rather than simply respond to pre-programmed threats
- **SWARMING ALGORITHMS FOR AGENTS/ROBOTS**
 - Many inexpensive robots
 - Each acting as a distributed sensor
 - Working together
 - Group intelligence greater than that acquired by any individual robot

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**SANDIA
TYPES OF AGENTS USED**

This information is contained in the text of the other sections.

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SANDIA
TYPES OF AGENTS USED

N/A

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SANDIA STATUS, RESULTS, AND POTENTIAL BATTLEFIELD APPLICATIONS

Cybersecurity

In March 2000 Sandia used a Red Team, a group of experts known for its computer break-in skills and frequently brought in to test the security of Government computers, to attack a five-computer network protected by the recently developed security bots (a software program that carries out a specific function, a robot) known as cyberagents. The cyberagents, without outside assistance, held off the human hackers for the whole 16-hour test.

Sandia is planning to expand this capability by training an agent to recognize and kill viruses, worms, and other invaders before they damage programs, systems, or networks.

Currently, the overall plan is to ready a basic set of agent capabilities for specific applications in business and Government by next year. A consumer release is at least 3 years away as Sandia says the agents must be "trained to protect a wider variety of services" before they can be of much use to the average household.

Robots

In tests currently being run, a number of robots are given the task of locating a sound source in an open field. When the robots begin their search they know nothing regarding the field in which

they are operating. They set off in a straight line and then stop after moving a short distance, record their position using the Global Positioning System (GPS), and listen for the hi-fi speaker using a simple microphone. They then broadcast to all the others what they've found: the volume of sound and where they are hearing it. This way each one of them has the knowledge of all the others and they can quickly build up a sound picture of the field. It is reported that typically the six-robot team using this technology has been able to locate the sound source four times faster than a much smarter solitary human.

Indications are that the robots are being modified to make them capable of not only using Sandia's intelligent agent software, but also cooperating with fixed computers in a large agent-based coalition for such missions as surveillance, reconnaissance, relay communication, target location, and mine-clearing. The agent architecture is highly secure, using the Cybersecurity approach discussed above, and is flexible enough so that agent software can be downloaded into the robots in real time whenever real-world sensors and effectors are needed to augment the coalition.

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SANDIA

STATUS, RESULTS, AND POTENTIAL BATTLEFIELD APPLICATIONS

CYBERSECURITY

- **RED TEAM ATTACK FAILED**
- **AGENTS BEING TRAINED TO RECOGNIZE AND KILL INVADERS**
- **AVAILABILITY**
 - Business and Government – next year
 - Consumer – 3 years

ROBOTS

- **FAVORABLE TEST RESULTS USING A TEAM OF 6 MECHANICAL ROBOTS**
- **MOVING TO:**
 - Outfit robots with intelligent agent software
 - Expand mission capabilities

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**SANDIA
REFERENCES**

Documents

N/A

Meetings, Briefings, and Demos

N/A

POCs

Shannon Spires (505) 844-4287 svspire@sandia.gov.

Dr. Sharon Stansfield (505) 844-1396 sastans@sandia.gov

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SANDIA REFERENCES

- DOCUMENTS
- MEETINGS, BRIEFINGS, AND DEMOS
- POCs

ACADEMIA

The team talked to a number of college professors. Although a considerable amount of work on intelligent agents appears ongoing, the team found none directed toward use by the military. The more notable professors talked to include:

- Dr. Erika Rogers, Associate Professor, Computer Science at California Polytechnic State University, <http://www.csc.calpoly.edu/~erogers/>
- Dr. Robin R. Murphy, Associate Professor, Department of Computer Science and Engineering & Cognitive and Neural Sciences, Department of Psychology, University of South Florida, (member 1998-99 DSSG), <http://www.csee.usf.edu/~murphy/>

- Dr. Timothy W. Finin, Professor, Computer Science and Electrical Engineering Department, University of Maryland Baltimore County (UMBC). He is also the director of the Institute for Global Electronic Commerce (IGEC), <http://www.csee.umbc.edu/~finin/>

- Dr. Katia Sycara, Senior Research Scientist and Associate Professor, Robotics Institute, School of Computer Science, Carnegie Mellon University, <http://www.cs.cmu.edu/~sycara/>

Since the work on the project was completed another professor, Dr. Gheorghe Tecuci at George Mason University, Fairfax, VA, was found to have done some intelligent agent work with DARPA and the U.S. Army. Some of his work is reported in building *Intelligent Agents*, Academic Press, 1998.

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ACADEMIA

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INDUSTRY AND ADDITIONAL WEBSITES

The team also met with and/or received briefings from companies working on intelligent agent software including:

- The Bios Group (<http://www.biosgroup.com/>) is developing intelligent agent software the Joint Staff. However, the work they are doing is not oriented toward a military use.
- Intelligent Agents, Dr. Paul Nielsen, 12 May 2000, Soar Technology (<http://www.sortech.com>) has developed intelligent agents that provide human-like behavior for simulation environments.

As part of its effort, the team also searched the Web. Although no efforts relating to military use of intelligent agents were found, the Web does contain a great deal of information about intelligent agents. The more interesting websites include:

University of Maryland, Agents page,
<http://www/cs/umbc.edu/agents/projects/>

The Multi-Agent Systems Laboratory,
<http://mas.cs.umass.edu/index.shtml>

Don Norman, Professor Emeritus, Departments of Cognitive Science and Psychology, UCSD <http://cogsci.ucsd.edu/~norman/>
MIT
<http://agents.www.media.mit.edu/groups/agents/>

University of Maryland Baltimore County (UMBC) Laboratory for Advanced Information Technology - website for information, resources newsletters and mailing lists relating to intelligent

information agents, intentional agents, software agents, softbots, knowbots, infobots, etc.

<http://agents.umbc.edu/about.shtml>.

The Agent Society is a new international industry and professional organization established to assist in the widespread development and emergence of intelligent agent technologies and markets <http://www.agent.org/>.

NASA's A Scalable Agent-based Information Retrieval Engine <http://saire.ivv.nasa.gov/saire.html>.

Object Services and Consulting, Inc. <http://www.objs.com/> and their OMG Internet Special Interest Group website at <http://www.objs.com/isig/> and their agent working group.

OMG Agent Working Group
<http://www.objs.com/isig/agents.html>.

Object Management Group's website
<http://www.omg.org/>

National and International Conferences,
<http://www.cs.washington.edu/research/agents99/> and
<http://www.isi.edu/isd/AA97/info.html>.

Site listing other agent related sites
<http://www.isi.edu/isd/AA97/related-sites.htm>.

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INDUSTRY AND ADDITIONAL WEBSITES

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APPENDIX A
GLOSSARY

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Appendix A

GLOSSARY

A2IPB	Automated Assistance for Initial Preparation of the Battlefield
AC2&ISRC	Aerospace Command and Control and Intelligence, Sensor, and Reconnaissance Center
ACTD	Advanced Concept Technology Demonstration
AEF	Aerospace Expeditionary Force
AFRL	Air Force Research Laboratory
ANTS	Autonomous Negotiating Team
AODA	Attack Operation Decision Aid
C ²	command and control
CAST	Cooperation Agent for Specific Tasks
CFF	call for fire
CMTC	Critical Mobile Targets Cell
CoABS	Control of Agent-Based Systems
CONOPS	Concept of Operations
CORBA	Common Object Request Broker Architecture
CRD	Capstone Requirements Document
DAML	DARPA Agent Markup Language
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
DSB	Defense Science Board
DSSG	Defense Science Study Group
DUSD(S&T)	Deputy Under Secretary of Defense (Science & Technology)

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E2W	Enhanced Early Warning
EUT	end user terminal
FBX	Field Battle Exercises
FOB	forward operating bases
FOL	forward operating locations
GPS	Global Positioning System
IDA	Institute for Defense Analyses
IGEC	Institute for Global Electronic Commerce
IMMACCS	Integrated Marine Multi-Agent Command and Control System
ISO	Information Systems Office (DARPA)
ISRBM	Intelligence, Sensor, and Reconnaissance Battle Management
JBWIF	Joint Battlespace Infosphere Wright Flyer
JEFX	Joint Expeditionary Force Experiment
JFC	Joint Forces Command
JFCOM	Joint Forces Command
JS	Joint Staff
JTF	Joint Task Force
LMATL	Lockheed Martin's Advanced Technology Laboratories

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NBC	nuclear, biological, chemical
OIS	Object Instance Store
ONR	Office of Naval Research
OSD	Office of the Secretary of Defense
POC	point of contact
ROE	rules of engagement
STOW	Synthetic Theater of War
TASK	Taskable Agent Software Kit
TCT	time-critical target
TCTA	Time Critical Target Analysis
TEL	transporter erector launcher
TTP	techniques, tactics, and procedures
UCSD	University of California, San Diego
UMBC	University of Maryland, Baltimore County

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE September 2000	3. REPORT TYPE AND DATES COVERED Final		
4. TITLE AND SUBTITLE The Commander's Edge: Intelligent Agent Software Applied to Battlefield Problems		5. FUNDING NUMBERS DASW-01-98-C-0067 CRP 1074		
6. AUTHOR(S) Lane B. Scheiber, Richard L. Craft, Grant A. Sharp				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Institute for Defense Analyses 1801 N. Beauregard Street Alexandria, Va 22311-1772		8. PERFORMING ORGANIZATION REPORT NUMBER IDA Document D-2475		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) FFRDC Programs 2001 N. Beauregard Street Alexandria, VA 22311-1772		10. SPONSORING/MONITORING AGENCY REPORT NUMBER		
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) Information being made available to those on the battlefield is increasing at a rapid rate. The emerging networks that the Services are readying for the battlefield offer improvement to commanders' ability to obtain information they need, when they need it, and in usable form. However, with this increase, battlefield commanders will also need tools with which to employ the information to make winning decisions in high tempo battles. Intelligent agents appear to be one tool for obtaining and displaying information in a timely fashion. The objective of this effort was to examine the extent to which the military is developing information technology, specifically intelligent agents, to assist commanders in obtaining decision superiority on the next-generation battlefield. The task attempted to answer the following questions: <ul style="list-style-type: none"> • Can intelligent agents aid in extracting data, processing data into knowledge useful to commanders, and presenting knowledge in a form commanders can quickly use? Can they do it in a timely fashion? • Can such intelligent agents be available in time to support the next-generation battlefield? • Can use of intelligent agents lead to decision superiority on the next-generation battlefield? IDA contacted the Joint and Service organizations and DoD agencies involved in the advanced concept definition and development of battlefield command and control (C2) systems. From these, we determined the main DoD and Service organizations working on information technology, specifically intelligent agents, including contractors and universities. The team obtained briefings by these organizations, reviewed documentation provided, and met with principals of ongoing agent-based efforts. It is clear that the military expects intelligent agents to provide a significant advantage for warfighters. However, although work is ongoing, the team found no applications ready for near-term fielding. While answers to the above questions are not yet clear, the Commander's Edge effort does provide a first-order look at how information technology, specifically intelligent agents, is being integrated into the systems to aid the commanders on the battlefield.				
14. SUBJECT TERMS information technology, intelligent agents, support for commanders, next generation battlefield, decision superiority, battlefield command and control systems, CoABS, IMMACCS, Time Critical Targets, TELs			15. NUMBER OF PAGES 137	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMIT OF ABSTRACT Unlimited	